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DLI, VISAR AND PDV MEASUREMENTS OF POLYURETHANE (PU) FOAM UNDER PYROTECHNIC SHOCK

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Need and associated studies

Basic needs :

- Impact time of PU block on an Al plate for two PU foams (two densities ρ=0.32 g/cm^3 and ρ=0.07 g/cm^3)

- Associated velocities of the foam and the Al structuration plate (Al alloy : Al6061 T6)

- Dynamic behavior of these PU foams (PolyUréthane) : optimization of parameters

Experimental and numerical studies :

Applied detonic and launchers experiments:

EOS of PU foams : high explosive and launchers (SYLEX and Garance) experiments. We have data on Al alloy.

Representative experiment : GOP API + Transmitter + PU foam + air gap + Al plate

GOP API = planar wave generator

Associated numerical simulations :

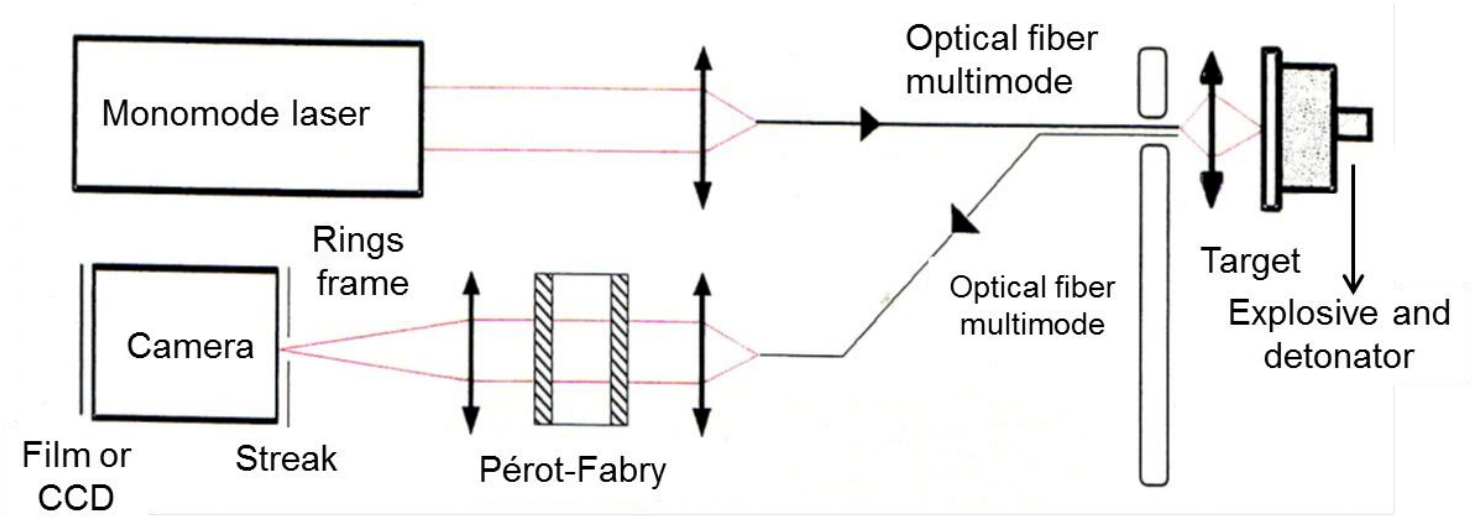
PU foam modeling : at high level, data bank from scientific literature and new results at low level (launchers Exp)

GOP API modeling : CEA/CESTA shots $\longrightarrow$ 3 EOS shots dedicated to debris and shrapnel issues for LMJ

Restitution of the two representative shots (geometries ≠) : GOP API + Trans. + PU ($\rho_{0.32}$) + air gap + Al plate

Velocity measurement diagnostics

Doppler Laser Interferometer with Pérot-Fabry and streak camera : DLI

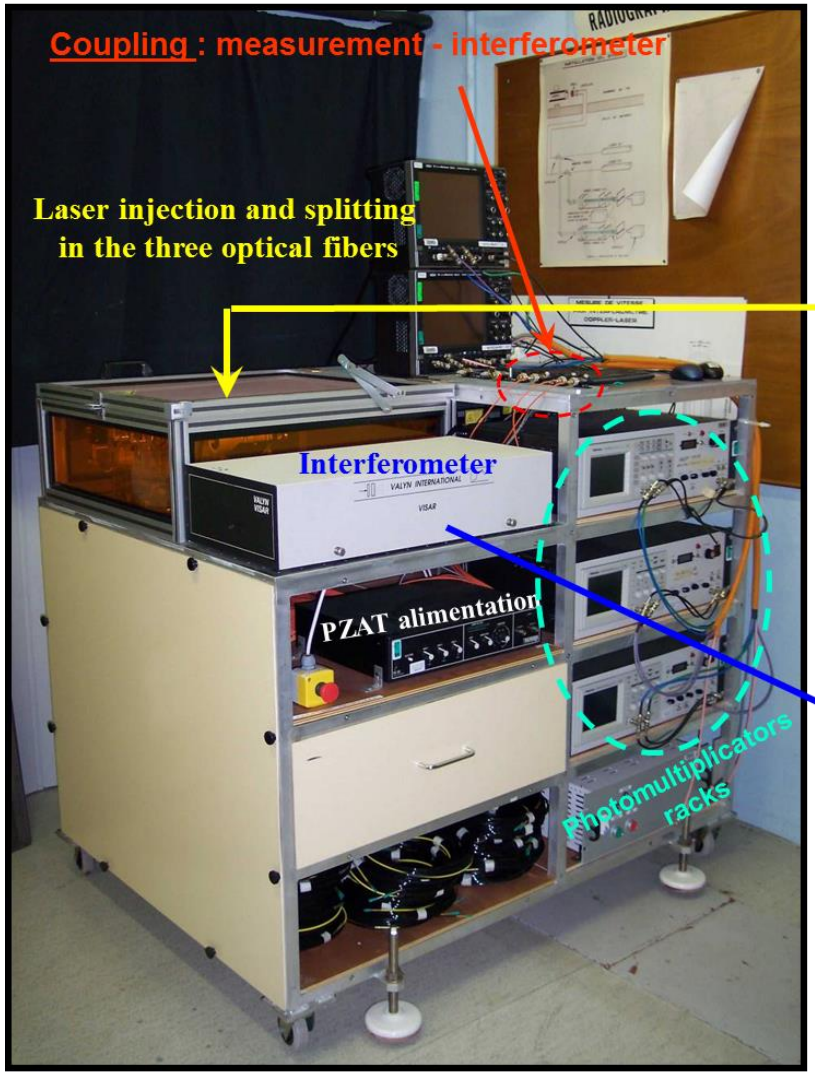


PDV rack : CEA (P. Mercier, J. Bénier,…) - IDIL rack

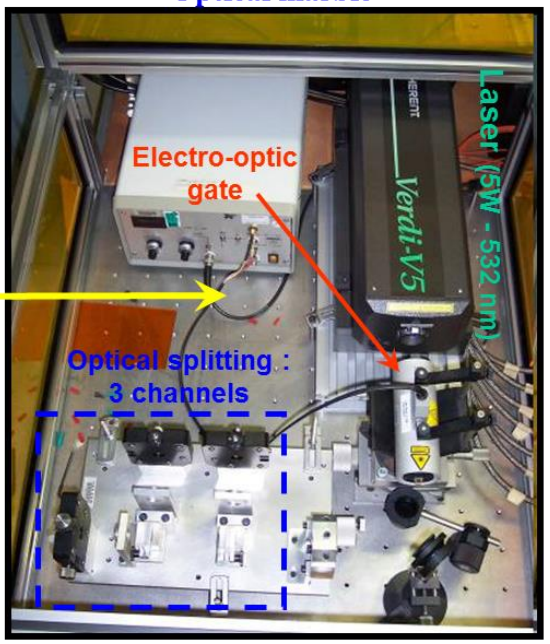
Classically, 4 channels with 4 more channels with time delay by strands optical fibers

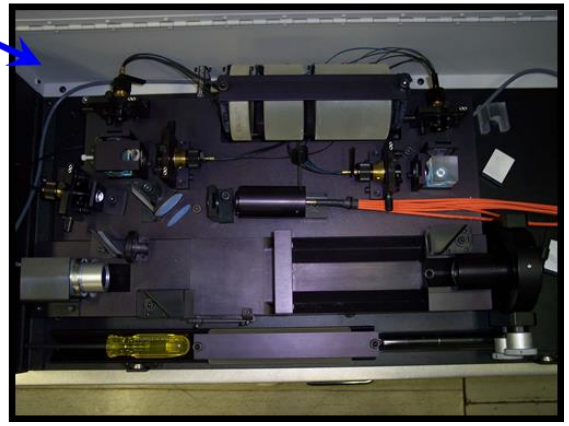
Velocity measurement diagnostics

Valyn VISAR used : 3 channels



Optical marble





Experimental results and PU foam modeling PU for ρ ~ 0.32 g/cm³

Shock states of PU foam :

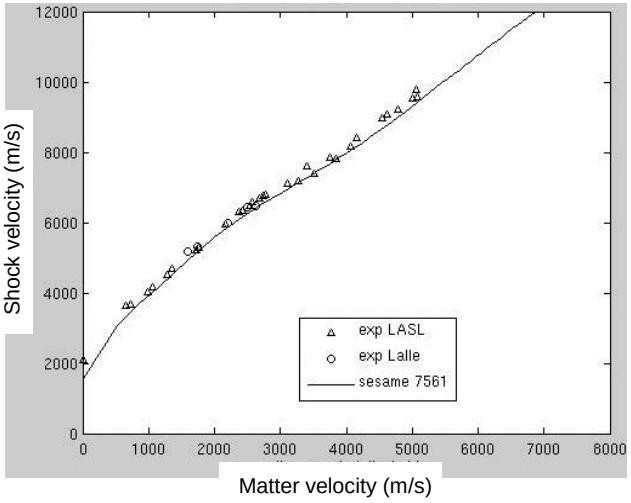
PORELAS model implemented in Hesione (Lagrangian and Eulerian code) :

- Compaction curve and associated coefficients are adjusted with launchers tests at CEA/CESTA
  (low level < 0.4 Gpa : hardening) V(t) measurement : **Fabry-Pérot + streak camera (DLI) or Valyn VISAR**

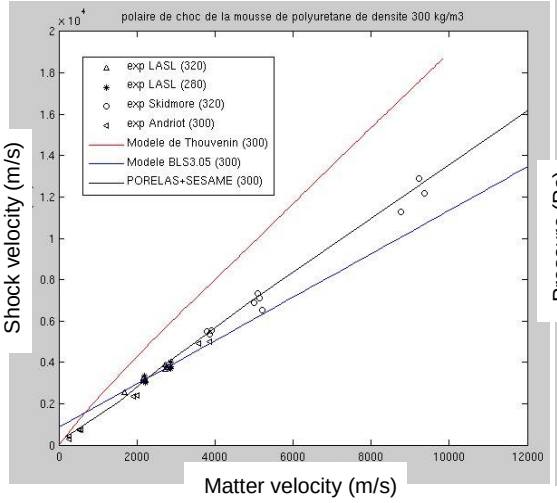
- Need data from 1.5 GPa to 5 GPa → SESAME (7561) EOS *(P. Lalle and P. Andriot experimental data)*
  V(t) measurements : **Fabry-Pérot + streak camera (DLI)**

Porous polyurethane

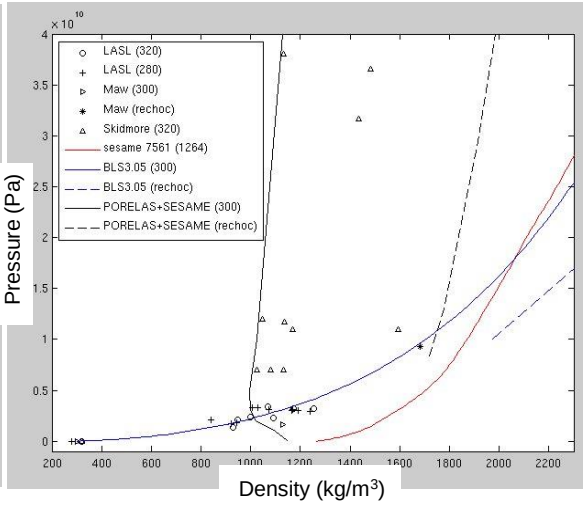
Compact polyurethane



Shock states



Shock states

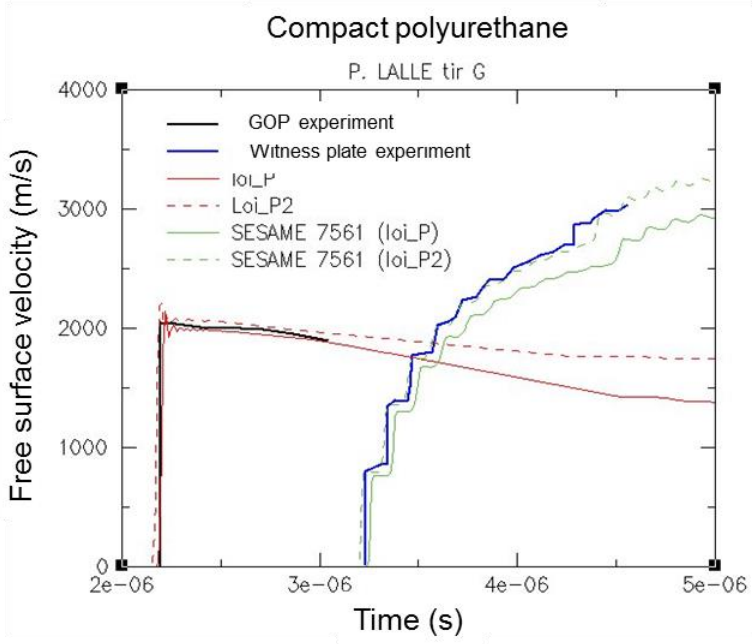


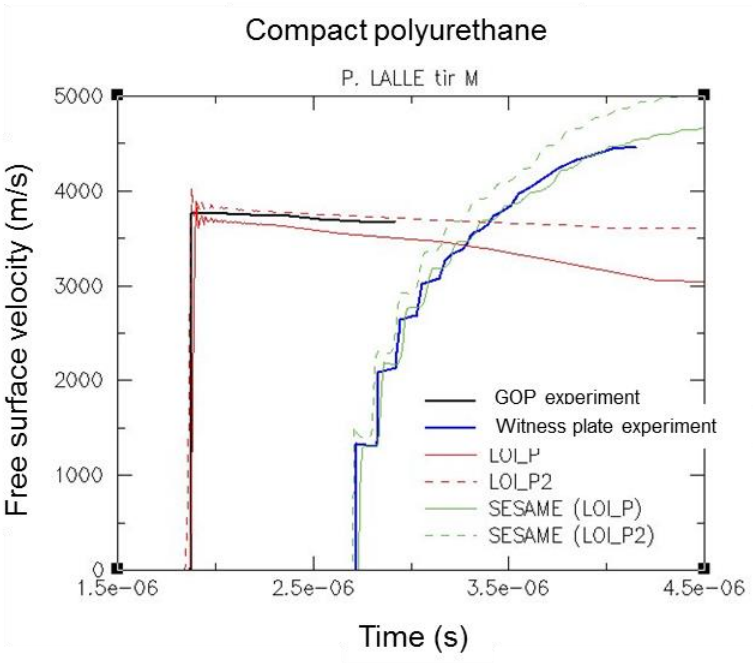
Conclusion on DLI and VISAR measurements

DLI (Fabry-Pérot) or Valyn VISAR measurements are sufficient for theses studies

Experimental results and PU foam modeling PU for ρ ~ 0.32 g/cm³

PU foam, release states after shock : **DLI (Fabry-Perot) measurements**





High level shots from Mr Pierre Lalle data

Good agreement with SESAME 7561 equation for shock states and for isentropic release

Conclusion on the modeling of PU 0.32 foam

PORELAS model with SESAME 7561 EOS for compact PU : good agreement with experimental results

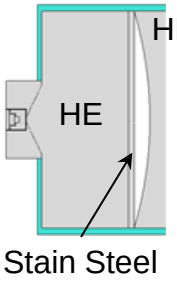
Conclusion on DLI and VISAR measurements

DLI (Fabry-Pérot) or Valyn VISAR measurements are sufficient for theses studies

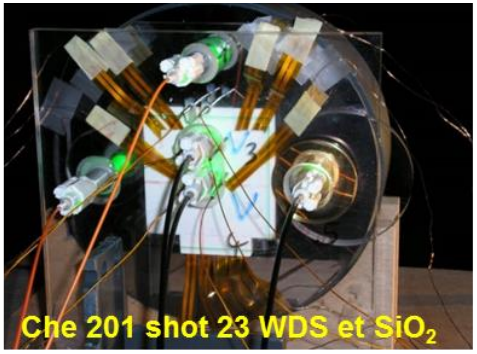
Experimental results and GOP API modeling

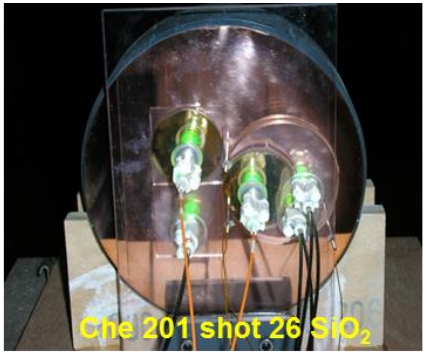
Three old shots (GOP API Φ200) : **DLI (Fabry-Perot) or Valyn VISAR measurements**

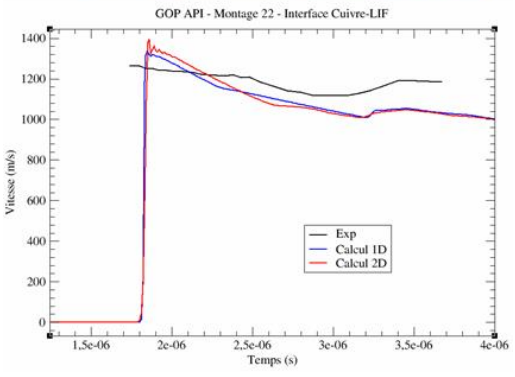
GOP API :

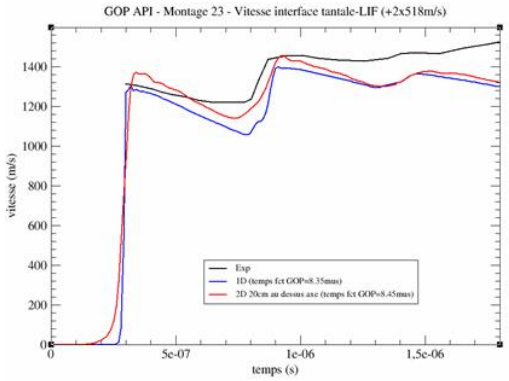


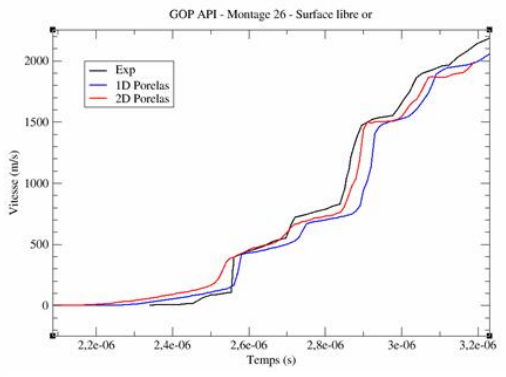
Shots dedicated to
- SiO_2 EOS for determination of operational size of LMJ optical debris shields
- EOS and et compaction of a foam (hardening studies)











Good agreement (1D et 2D Num. Simu. and Exp. Results) : chronometry et associated matter velocities

Conclusion on DLI and VISAR measurements

DLI (Fabry-Pérot) or Valyn VISAR measurements are sufficient for theses studies

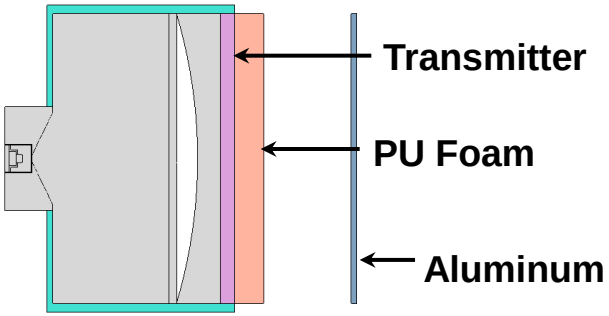
First representative experiment : diagnostics and associated results

The diagnostics and associated results for the high explosive shots :

			Results :
Transmitter : 2 DLI (Fabry-Pérot and streak camera)		Conditions at foam entry	**OK**
Foam :	**2 VH foam exit**	Matter velocity	**OK**
	2 VISAR on Al anvil	Foam state under shock	**OK**
	1 PDV on aluminized mylar	Foam state under shock	**OK**
	4 carbon piezoresistives gages σ(t)	Foam state under shock	**OK**
Al plate :			
uphill :	2 piezoelectric probes	Impact chronometry on Al plate	**OK**
	2 carbon piezoresistives gages σ(t)	Foam and Al states under shock	**No results (Particles)**
downhill :	2 piezoelectric probes	Shock chronometry	**OK**
	2 carbon piezoresistives gages σ(t)	Al6061T6 state under shock	**OK**
	1 VISAR and PDV on Al free surface	Al6061T6 state under shock	**OK**

Which hypothesis for associated numerical simulations of experiments ?

GOP API Φ100

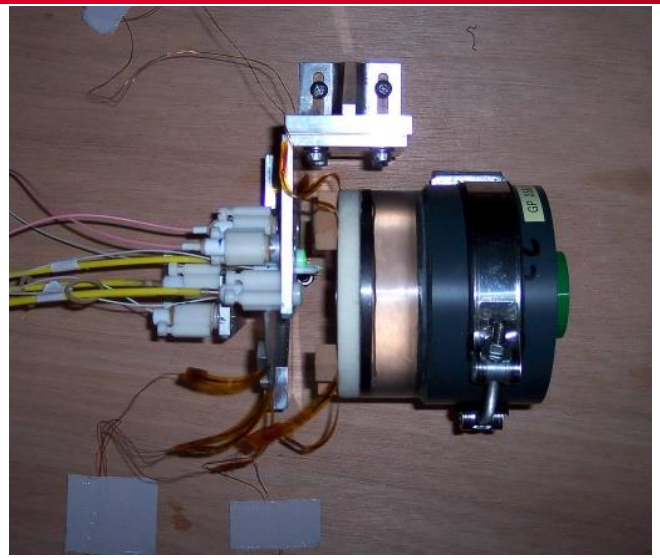


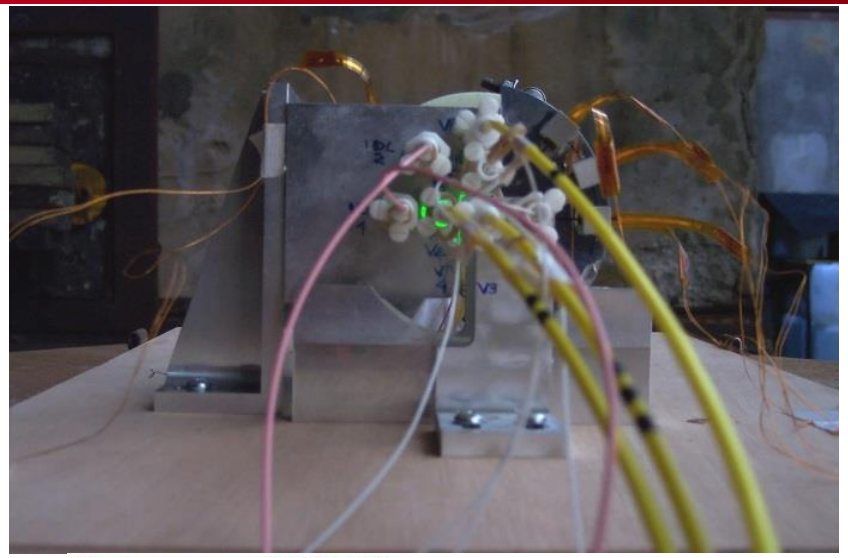
1) GOP API model validated on previous shots

2) PORELAS model + SESAME 7561 EOS for compact PU

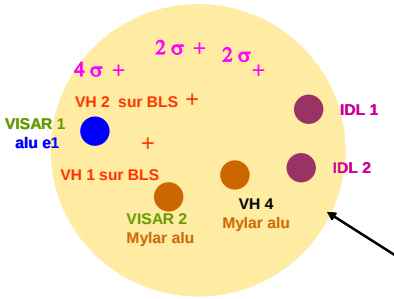
3) EOS, behavior laws and spall strength from CEA data book

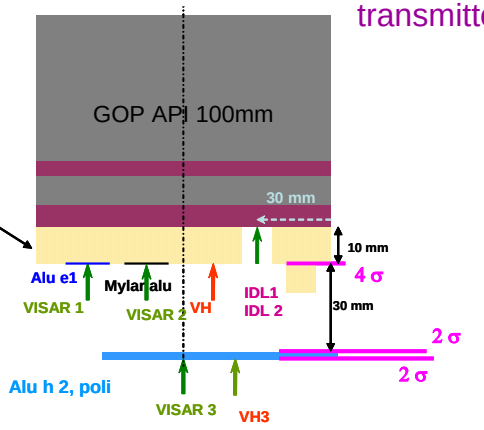
First representative experiment : pictures and instrumentation description

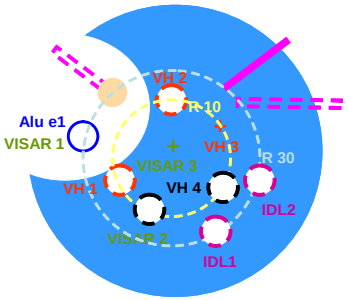




Montage mesures CHE201 SN3

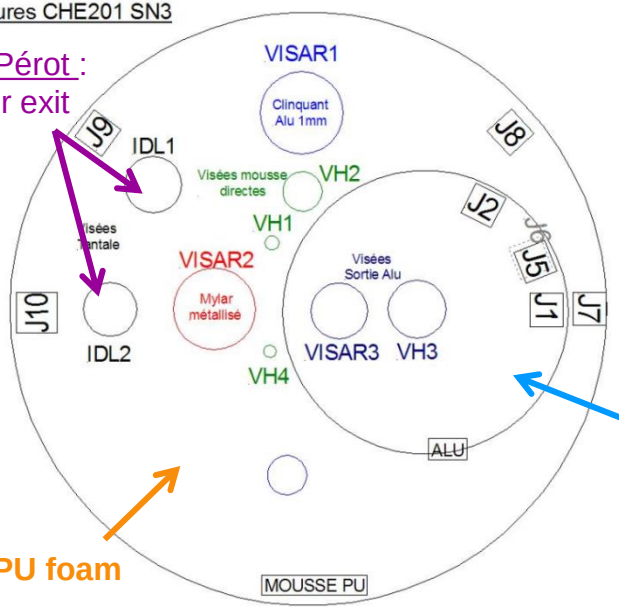






VH = PDV probe

DLI Fabry-Pérot : transmitter exit

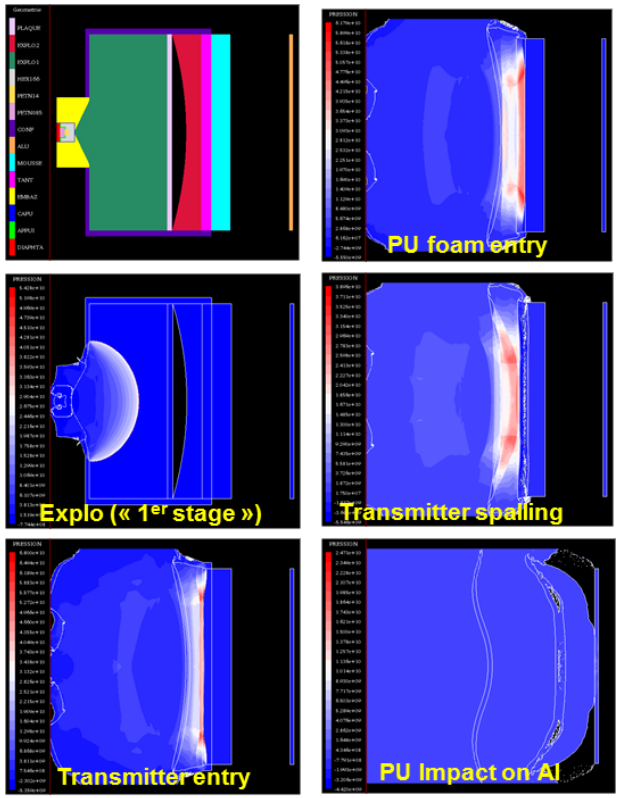


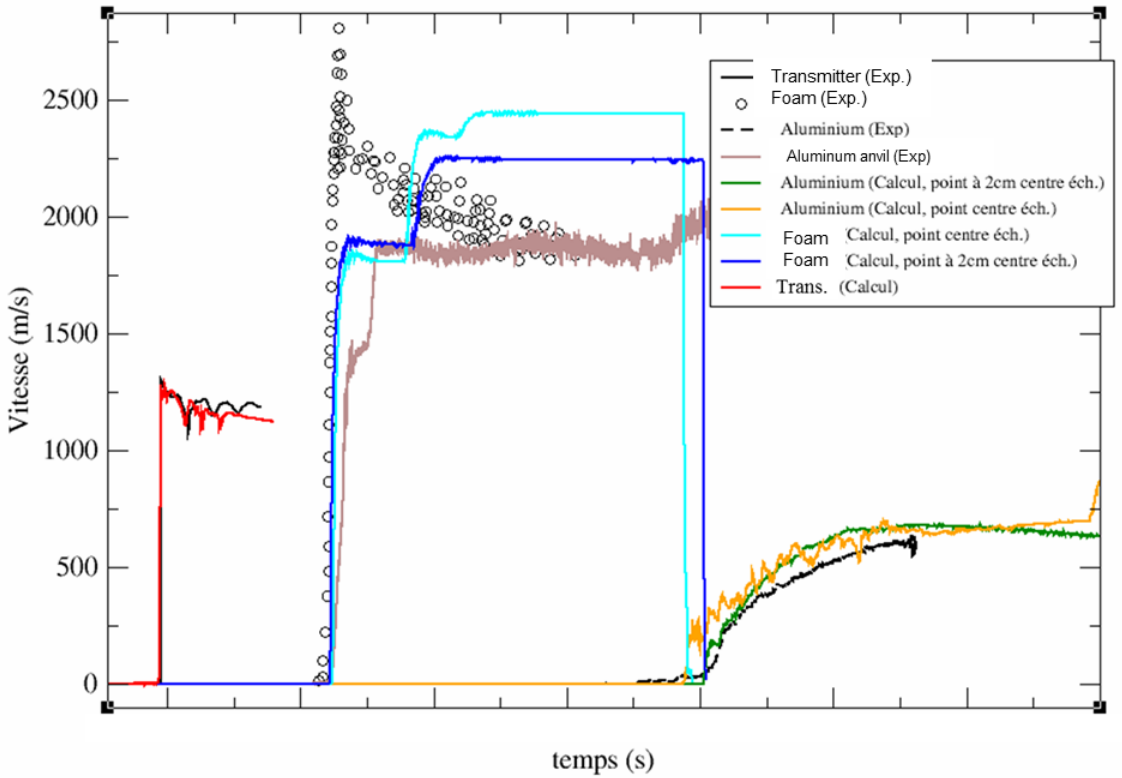
Al plate

PU foam

J_i : piezoelectric probes or carbon gages

Experimental results on first shot and associated numerical simulations





Transmitter : good agreement Exp. / Num. Simu., but detached spall in Exp. and closed in Num. Simu. **DLI ok**

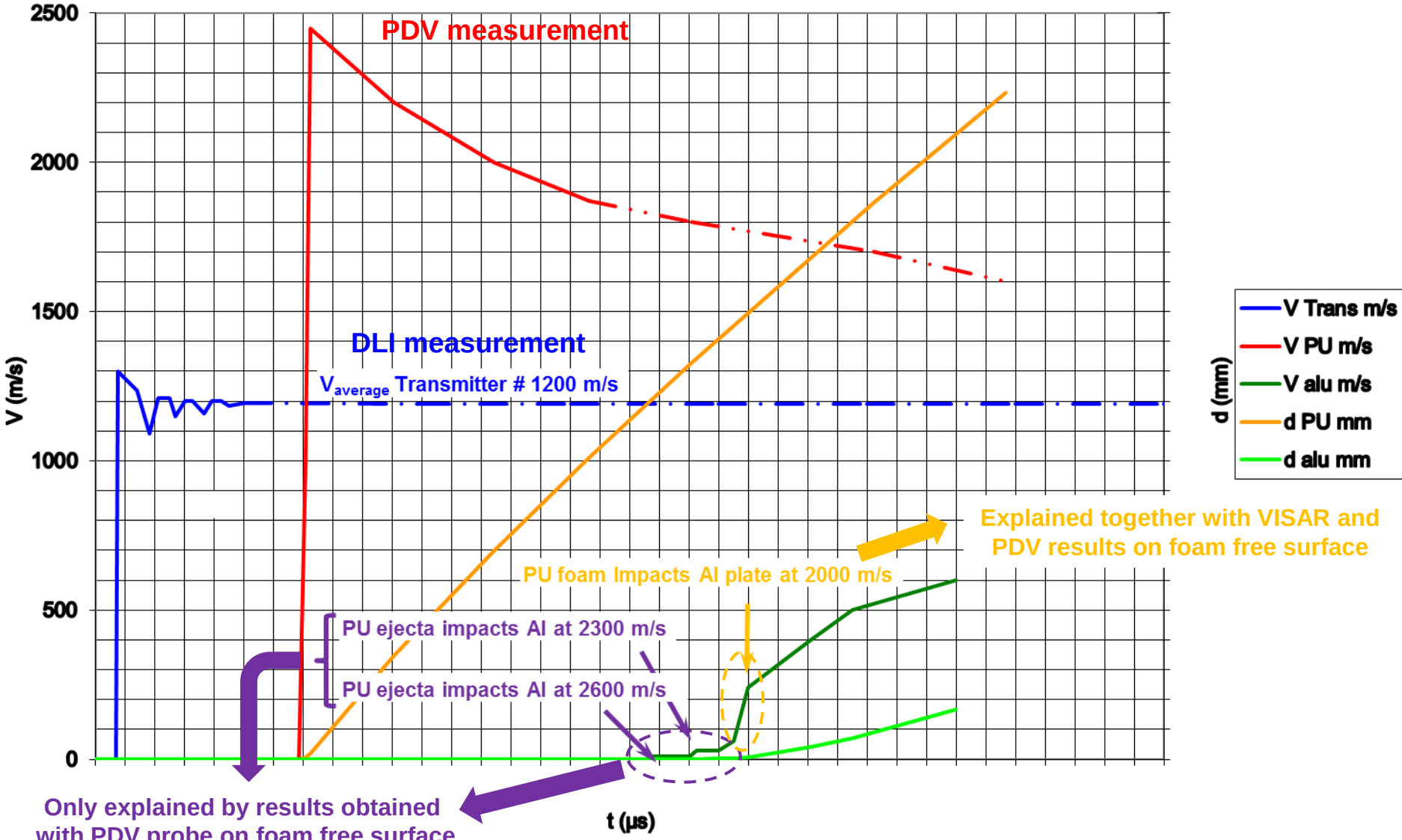
Foam : 1) good agreement for anvil (2nd shock in Num Sim due to spall closure in Trans) **VISAR ok but**

2) Free surface PDV measurements show velocities of small particles ejected from PU foam

Foam impact on Al6061 T6 plate : well reproduced by Num. Simu. **VISAR and VH Ok**

Experimental results on first shot and qualitative analyse

Diagrams V(t) and d(t) : PU foam arrival on Al plate, chronometry and associated velocities

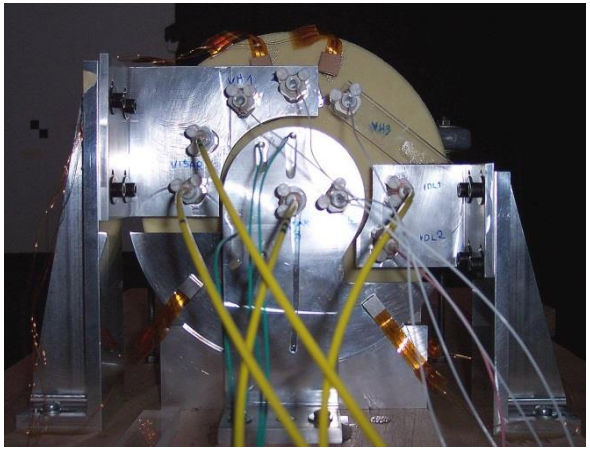


Second GOP API shot : representative configuration

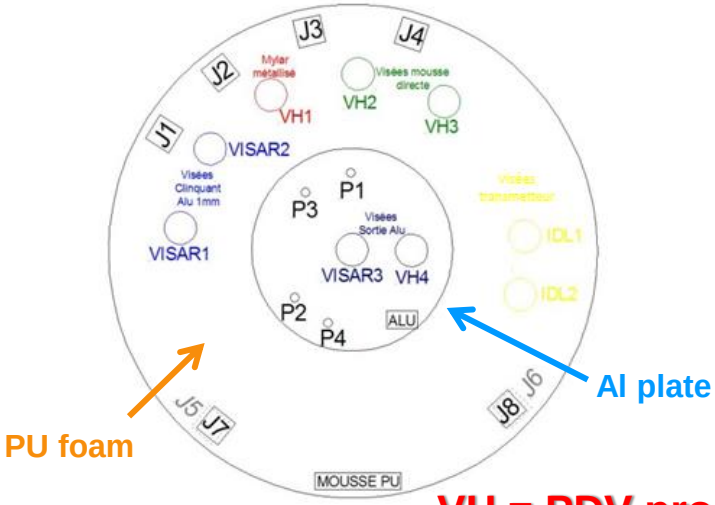
Repeat shot : GOP API Φ100 + Trans. + PU 0.32 (x_1 mm) + air gap + 6061 T6

Nominal shot : GOP API Φ200 + Trans. + PU 0.32 (x_2 mm) + air gap + 6061T6

Slightly different conditions
→ Second optimization



J_i : piezoelectric probes or carbon gages

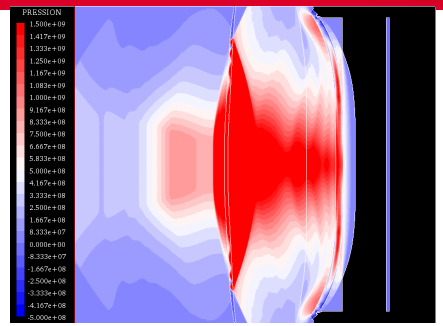


VH = PDV probe

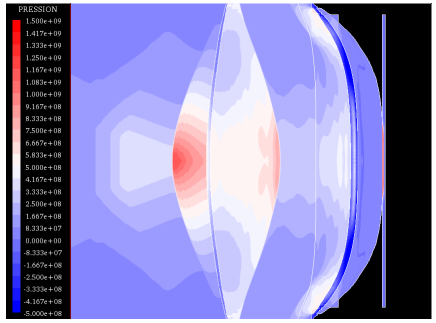
Associated diagnostics :

	Results :
Trans. : 2 DLI (Fabry-Pérot) and streak camera)	Ok
Foam : 2 VH on foam exit	Ok
2 VISAR on Al anvil	Ok
1 PDV on aluminized mylar	Ok
4 carbon piezoresistives gages σ(t)	Ok
Al plate :	
uphill : 2 piezoelectric probes	Ok
2 carbon piezoresistives gages σ(t)	No results (particles)
downhill : 2 piezoelectric probes	Ok
2 carbon piezoresistives gages σ(t)	Ok
1 VISAR and PDV on Al free surface	Ok

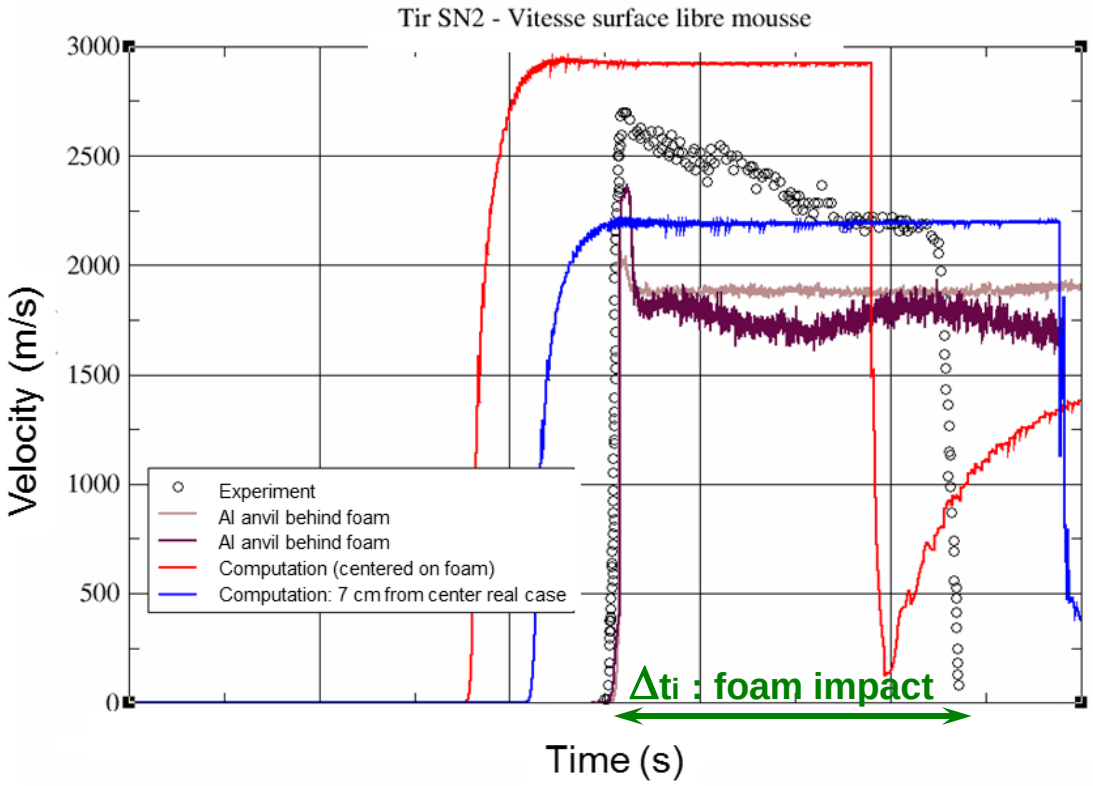
Foam exit : numerical predictions for the nominal GOP API shot



Foam velocity setting



PU foam impacts Al6061T6

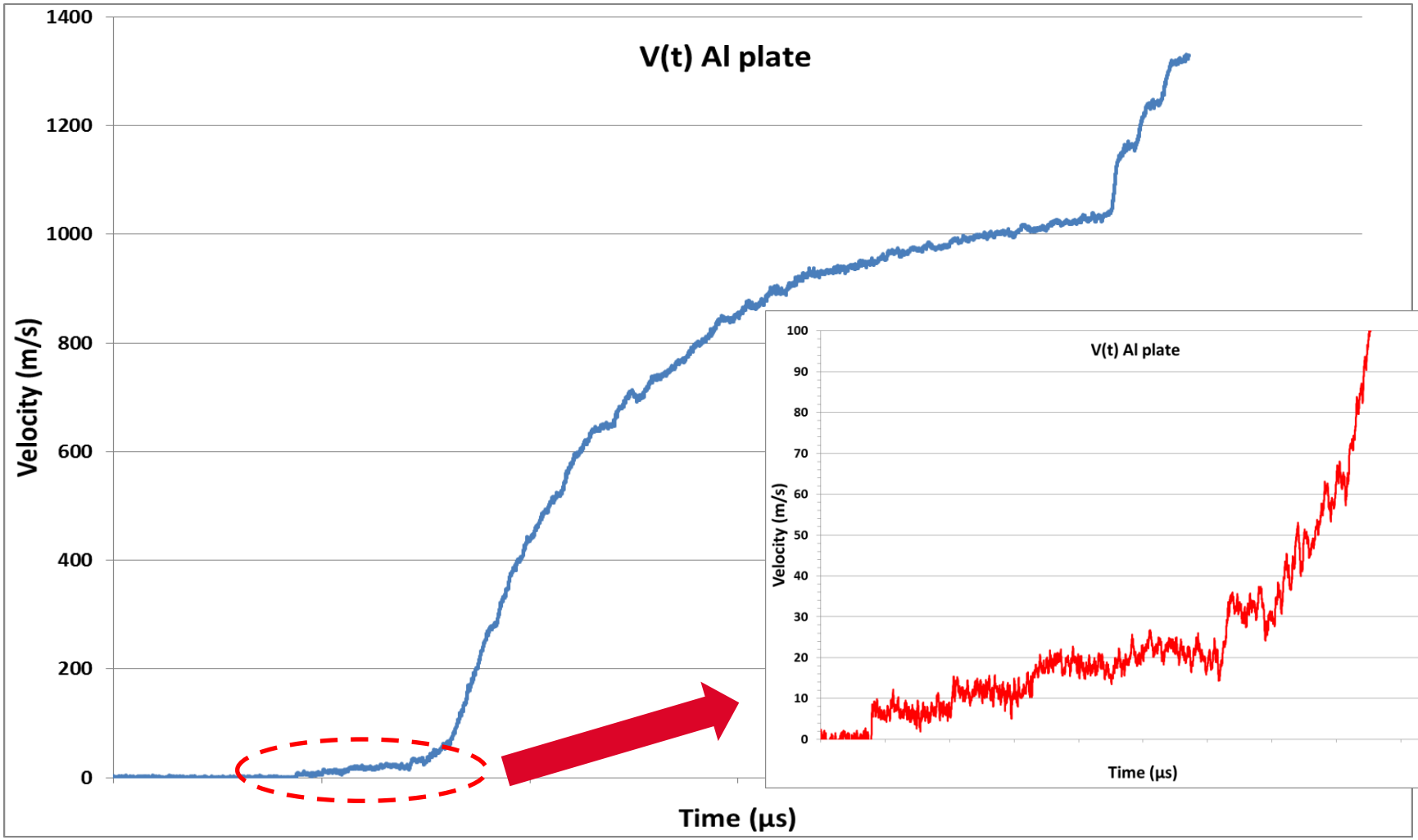


- **PDV probe shows ejection of PU foam particles at the free surface : Real value of Δti time of foam impact**

- good agreement Num Sim / Exp.
  - Free surface velocities (central/remote) are between measurement (2D effect)
  - Time difference due to the transmitter spalling : not correctly calculated

Foam impact on Al6061 T6 plate : well reproduced by Num. Simu. **VISAR and VH Ok**

Velocity of aluminum plate



PDV measurement of foam ejection → Particles V(t) → **Accurate determination of foam impact time**

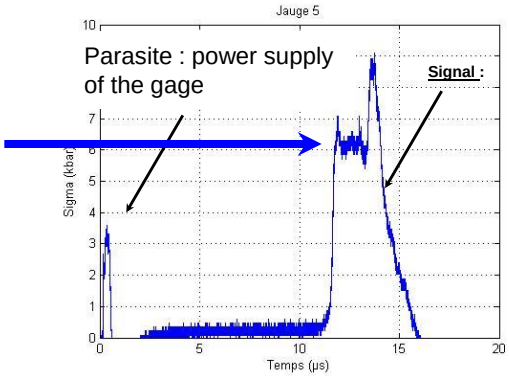
Associated velocity measurement of Al plate velocity → **Impacting particles weighing**

Conclusions

Experimental campaign :

- Experimental results very successful for all diagnostics

- **Confirmation of the interest of PDV for particles velocity measurement**
  (same results as for foil fragmentation due to laser deposition)



- **Carbon piezoresistive gages σ(t) : good for this measurement**
  (not depicted in this talk)

- **DLI and Valyn VISAR : good results for EOS measurements**

Numerical simulations :

- PU foam modeling validated

- GOP API model validated

- Spalling of transmitter to improve

Same type of results for the PU foam ρ =0.07 g/cm³ :

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